NOTES

The Crop Moisture Index: Unnatural Response to Changes in Temperature

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ABSTRACT

A sensitivity study conducted on the Crop Moisture Index revealed that in some cases the index indicates wetter conditions as temperature increases. The unnatural response is due to the formulation of the evapotranspiration anomaly term. Conditions under which the unnatural behavior occurs are described. A reformulation of the evapotranspiration anomaly term which removes the unnatural response is presented.

The Crop Moisture Index (CMI), published weekly from April through October in the *Weekly Weather and Crop Bulletin*, is designed to provide information about broad-scale moisture conditions (Palmer, 1968). Computation of the CMI involves the use of weekly values of temperature and precipitation to compute a simple moisture budget. Variables from the moisture budget computation are compared to long-term average values and modified by empirical relations to arrive at a final CMI value. Tables 1 and 2 list the terms and relationships used to compute the CMI. Temperature is used to estimate potential evapotranspiration using the method devised by Thornthwaite (1948), which yields larger potential evapotranspirations for higher temperatures. A sensitivity study conducted on the CMI showed that an increase in the CMI may occur with an increase in potential evapotranspiration. An increase in the value of the CMI indicates wetter moisture conditions and there is no case in nature where an increase in potential evapotranspiration will produce wetter moisture conditions.

Table 3 shows calculations of the CMI that illustrate the unnatural response of the CMI. Cases 1 and 2 shown in Table 3 differ only by the potential evapotranspiration. In case 1 the precipitation is greater than the potential evapotranspiration. In the CMI calculation procedures this condition causes the actual evapotranspiration to equal the potential evapotranspiration and the excess precipitation not removed by evapotranspiration to appear in the recharge term.

In case 2 the precipitation is less than the potential evapotranspiration and under these conditions the calculations show that the actual evapotranspiration is equal to the precipitation plus 0.25 inches of water from the subsurface soil moisture. The loss of soil moisture and reduced evapotranspiration below the potential evapotranspiration in case 2 suggest that case 2 represents a drier condition than case 1, which had soil moisture recharge and no reduction of evapotranspiration. However, calculations of the CMI for case 2 give a higher value than for case 1 (0.48 vs. 0.35), suggesting that case 2 represents the wetter conditions.

The specific formulation of the abnormal evapotranspiration term is the source of the unnatural behavior of the CMI. The abnormal evapotranspiration is computed as the difference between the actual evapotranspiration and the climatologically expected evapotranspiration. The expression for the abnormal evapotranspiration takes different forms depending on the prevailing moisture conditions. When the potential evapotranspiration minus the precipitation is less than the previous week's surface soil moisture the expression becomes

$$\begin{aligned}\mathrm{ET}-\mathrm{CET}&=\mathrm{Ls}+\mathrm{Lu}+\mathrm{P}-(\mathrm{alpha}\cdot\mathrm{PE})\\&=\mathrm{PE}-\mathrm{P}+[\mathrm{PE}-\mathrm{P}-(\mathrm{PE}-\mathrm{P})\cdot\mathrm{S'u}/\mathrm{AWC}]\\&\qquad+\mathrm{P}-\mathrm{alpha}\cdot\mathrm{PE}\\&=\mathrm{PE}-(\mathrm{alpha}\cdot\mathrm{PE})\\&=\mathrm{PE}\cdot(1-\mathrm{alpha}).\end{aligned}\tag{1}$$

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TABLE 1. Relationships used to compute the Crop Moisture Index (from Palmer 1965; Sadowski, 1975).

Ls	$= PE - P$ or $S's$, whichever is smaller
Lu	$= (PE - P - Ls) \cdot S'u/AWC$ or $S'u$, whichever is smaller
Ss	$= S's - Ls$, where $Ss \leqslant 1.0$
Su	$= S'u - Lu$, where $Su \leqslant AWC - 1.0$
R	$= Su + Ss - S's + S'u$, if $R > 0.0$, $R + S'u + S's \leq AWC$
RO	$= (S's - Ls + S'u - Lu) - AWC$, if $RO > 0.0$
ET	$= Ls + Lu + P$
alpha	$= \overline{ET}/\overline{PE}$
CET	$= \text{alpha} \cdot PE$
DE	$= (ET - CET)/\text{alpha}^{\frac{1}{2}}$
Y_i'	$= 0.67\ Y_{i-1}' + 1.8\ DE$
Y_i	$= Y_i'$, if $Y_i' \leq 0.0$
Y_i	$= M\ Y_i'$, if $Y_i' > 0.0$
M	$= \frac{1}{2}(S's + S'u + Ss + Su) \cdot AWC$
H	$= G_{i-1}$, if $G_{i-1} < 0.5$
H	$= 0.5$, if $G_{i-1} = 0.5–1.0$
H	$= 0.5\ G_{i-1}$, if $G_{i-1} > 1.0$
G_i	$= G_{i-1} - H + M\ R + RO$
CMI	$= Y_i + G_i$

Eq. (1) shows that when the potential evapotranspiration minus the precipitation is less than the surface soil moisture an increase in potential evapotranspiration will result in an increase in the abnormal evapotranspiration except when alpha equals its maximum value of 1.

When the potential evapotranspiration minus the precipitation is greater than the surface soil moisture and the subsurface moisture loss is less than the stored subsurface soil moisture the expression for the abnormal evapotranspiration is

$$\begin{aligned}
ET - CET &= Ls + Lu + P - (\text{alpha} \cdot PE) \\
&= S's + [(PE - P - S's) \cdot S'u/AWC] \\
&\qquad + P - (\text{alpha} \cdot PE) \\
&= S's + (S's \cdot S'u/AWC) + P - (P \cdot S'u/AWC) \\
&\qquad + (PE \cdot S'u/AWC) - (\text{alpha} \cdot PE) \\
&= S's \cdot (1 - S'u/AWC) + P \cdot (1 - S'u/AWC) \\
&\qquad + (PE \cdot S'u/AWC) - (\text{alpha} \cdot PE) \\
&= (S's + P) \cdot (1 - S'u/AWC) \\
&\qquad + (PE \cdot S'u/AWC) - (\text{alpha} \cdot PE) \\
&= (S's + P) \cdot (1 - S'u/AWC) \\
&\qquad + PE \cdot (S'u/AWC - \text{alpha}). \qquad (2)
\end{aligned}$$

Eq. (2) shows that when the subsurface soil moisture divided by the available water capacity is greater than alpha an increase in the potential evapotranspiration will result in an increase in the abnormal evapotranspiration. Eq. (2) is valid until the loss of soil moisture is greater than the stored soil moisture. Under these extremely dry conditions the abnormal evapotranspiration decreases with increasing potential evapotranspiration. Eqs. (1) and (2) reveal that there is a wide range of conditions under which the CMI will respond in an unnatural way to changes in temperature.

TABLE 2. Terms used to compute the Crop Moisture Index (from Palmer, 1965; Sadowski, 1975).

P	precipitation
PE	potential evapotranspiration
$\overline{PE}$	climatologically normal PE
Ls	surface soil moisture loss
Lu	subsurface soil moisture loss
Ss	surface soil moisture
Su	subsurface soil moisture
S's	previous week's surface soil moisture
S'u	previous week's subsurface soil moisture
ET	actual evapotranspiration
$\overline{ET}$	climatologically normal ET
CET	climatologically expected evapotranspiration
ET-CET	abnormal evapotranspiration
alpha	coefficient of evapotranspiration
DE	evapotranspiration anomaly for the week
Y'	first approximation of Y
i, i−1	reference to this week and last week
Y	evapotranspiration anomaly index
M	percent of field capacity
AWC	available water capacity
R	recharge
RO	runoff
G	excess moisture index
H	return to normal factor
CMI	Crop Moisture Index

The unnatural response of the CMI to changes in temperature is due to the dependence of the abnormal evapotranspiration term on the magnitude of the potential evapotranspiration. The abnormal evapotranspiration is the actual evapotranspiration minus the climatologically expected evapotranspiration and as such is a measure of climatologically unusual moisture stress. Another way to assess unusual moisture stress is to compare the weekly ratio of actual to potential evapotranspiration to the climatologically normal ratio of actual to potential evapotranspiration. The evapotranspiration anomaly for the week would

TABLE 3. Calculations of the CMI for two potential evapotranspirations. Initial conditions: $P = 0.5$ inches, $S's = 0.0$ inches, $S'u = 3.0$ inches, $AWC = 6.0$ inches, alpha $= 0.4$, $Y_{i-1}' = 0.0$, $G_{i-1} = 0.0$.

	Case 1	Case 2
PE	0.25 inches	1.0 inch
PE–P	−0.25 inches	0.5 inches
Ls	−0.25 inches	0.0 inches
Lu	0.0 inches	0.25 inches
ET	0.25 inches	0.75 inches
CET	0.1 inches	0.4 inches
ET–CET	0.15 inches	0.35 inches
DE	0.24	0.55
Y_i'	0.43	1.00
M	0.52	0.48
Y_i	0.22	0.74
R	0.25	0.0
G_i	0.13	0.0
CMI	0.35	0.48

then be

$$DE = f(ET/PE - \overline{ET}/\overline{PE}) \quad (3)$$

instead of the present formulation

$$DE = f(ET - \overline{ET}/\overline{PE} \cdot PE). \quad (4)$$

There are several reasons for using Eq. (3) as the expression for the evapotranspiration anomaly: 1) Eq. (3) eliminates the unnatural response of the CMI to changes in temperature; 2) it makes sense as a measure of moisture stress; and 3) it maintains the idea of Palmer (1968) to consider a moisture situation stressful only if it deviates from the average condition.

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